In August, 2011, EPA disapproved Missouri's numeric nutrient criteria (NNC) for lakes (10 CSR 20-7.031 (3)(N)), with the exception of Table M. Specifically, EPA stated that the rationale that was submitted did not provide a convincing link between the criteria and any designated use (DU) of lake waters. Furthermore, they charged that the criteria failed to protect a specific DU, warm water aquatic life. In response, Missouri DNR's Water Protection Program (WPP) has revised the proposed criteria in order to answer these concerns.

Lakes in Missouri that are regulated by water quality standards are presumed to support at minimum the following uses: Aquatic habitat protection (AQL), human health protection (HHP), whole body contact recreation – Category B (WBC-B), and Secondary contact recreation (SCR). A number of lakes have more sensitive DU, including whole body contact recreation – Category A (WBC-A), and drinking water supply (DWS) (Missouri Secretary of State, 2014).

A complicating factor in deriving appropriate NNC is that, in Missouri lakes, which are almost all man made impoundments, suitable trophic conditions for supporting the various DUs do not coincide, and are often at odds with each other. In particular, support of AQL depends in many situations on a relatively high availability of nutrients to supply the food chain (Michaletz, Obrecht, & Jones, 2012; Downing & Plante, 1993; Ney, 1996). In contrast, suitability of lake waters for DWS and WBC is favored by lower nutrient content, which reduces risks associated with reduced water transparency and the production of algal toxins (Falconer, et al., 1999; Knowlton & Jones, 2003).

It appears there is geographical variation to normally occurring trophic conditions in Missouri lakes. Lakes in the northern and western parts of the state (Central Dissected Plains and Osage Plain) tend to be more eutrophic and hypereutrophic while lakes in the Ozark Highlands regions are generally mesotrophic and oligotrophic. Lakes in the Ozark Border region have a range of trophic character that runs lower than the Plains region but higher than the Ozark Highlands (Jones, et al., 2008). This variation was reflected in the rule which was disapproved and remains so in the proposed rule.

The proposed rule further divides NNC for lakes within each of these regions according to the water body classifications that are listed in the state's water quality standards. That way, it is expected that the NNC for any given lake will more closely fit its prevailing DU. A description of the lake types, their average size, and geographical distribution are in Table 1.

Table 1: Distribution of classified lakes (≥ 10 ac) by lake class and lake eco-region.

Lake Class	Description	Number of Lakes			Average Size (ac)
		Plains	Ozark Border	Ozark Highland	
L1	Lakes used primarily for public drinking water supply	103	3	5	95
L2	Major reservoirs	5	0	10	16,245
L3	Other lakes which are waters of the state (WBC-A)	40	29	39	105
	Other lakes which are waters of the state (WBC-B)	485	122	196	31

Response Variables

The primary mechanism of water quality impairment from nutrients is the growth of algae which, if left unchecked by a limit to the presence of total phosphorus (TP) and total nitrogen (TN), results in several adverse consequences. These include reductions in dissolved oxygen caused by algal respiration and decay, unsightly blooms, reduced water transparency and, in some cases, the production of microcystins and other toxins by certain algae species, notably the blue-greens.

The most common method of measurement of the abundance of algae in a water body is the concentration of chlorophyll-a (Chl-a). There are many variables that can affect algae response to nutrient concentration, including lake depth, lake area, watershed characteristics, and hydraulic residence time. However, analyses of water quality data within each of the lake regions, and within each lake classification, indicate significant correlations between TP and Chl-a. Correlations between TN and Chl-a are generally not as strong, but are nevertheless significant.

The other principal response variable is Secchi depth. This is primarily of concern in consideration of WBC recreation. Easily measured, it relates inversely to lake turbidity. While turbidity is influenced by the inflow of non-volatile suspended solids (NVSS), there is nevertheless a strong relationship between TP and Secchi depth. The relations of Secchi depth to Chl-a and TN are less so, however for Chl-a, it is still significant in the vast majority of Missouri lakes where NVSS < 10 mg/L (Knowlton & Jones, 2003).

While there is truth to the dictum "correlation is not causation", the relationships between nutrients in solution, algal growth, and turbidity are well established (Carlson, 1977; Dillon & Rigler, 1974). Given that response variables present more direct measures of risk to the DU of a lake, the question is, what should the target be? It depends on the prevailing DU of the lake.

Criteria for TN and TP for each lake type within each of the lake eco-regions are derived from regressions of the response variables to each of the nutrients. Data that are used in these regressions are in the form of yearly geometric means for individual lakes, grouped by lake classification and region. This approach is intended to account for the possible seasonal lag times between nutrient loading and algal response.

Public Drinking Water Supply

Eutrophication in lakes that are sources for public drinking water supply can give rise to several issues, including taste and odor problems, higher treatment costs, and potential health hazards. The last item may come in the form of cyanotoxins (where treatment is minimal or lacking) or disinfection by-products, notably tri-halo-methane.

The presence of cyanobacteria within algae blooms increases the potential of toxin production, of which the most common is microcystin. A hepotoxin, microcystin[1] has been documented to pose chronic and

[1] Microcystins are a family of compounds. The most extensively studied member is microcystin-LR (5R,8S,11R,12S,15S,18S,19S,22R)-15-[3-(diaminomethylideneamino)propyl]-18-[(1E,3E,5S,6S)-6-methoxy-3,5-

acute health risks to livestock, pets, and humans. The World Health Organization (WHO) has adopted a provisional guideline value for lifetime exposure of 1.0 µg/L (1,000 ng/L) for microcystin.[2] (Falconer, et al., 1999)

Graham et al (2004) found that in Missouri and several adjacent states, microcystin is common in lakes but generally at low levels. Median concentrations were 0 ng/L in the Ozark Highlands and Osage Plains and 2 ng/L in the Dissected Till Plains. Maxima were 43, 189, and 2,933 ng/L respectively for these same regions. While only 2 percent of the sites in the study area had concentrations greater than the WHO recommended level of 1,000 ng/L, that is enough to raise concerns of potential exposure for some drinking water customers.

Cyanobacteria release other compounds that have been identified as causes of taste and odor problems in drinking water. Geosmin (trans-1, 10 dimethyl-trans-9-decalol) and MIB (2-methyl isoborneol) have been strongly associated with blue-green algae blooms. Smith et al (2002) found a strong predictive relationship between geosmin and Chl-a concentrations. Taste and odor problems would cease when Chl-a concentrations are maintained at a level below 10 µg/L.

Walker (1985) determined a non-linear relationship between Chl-a concentration and algal bloom frequency. The latter increased exponentially when Chl-a levels exceeded 10 µg/L. This corresponds to the same benchmark noted by Falconer (1999) and Downing et al (2001). Based on this information, Chl-a criteria for L1 lakes will be no greater than 10 µg/L.

Whole Body Contact

High algae production in lakes has implications for WBC recreation that parallels the health issues associated with drinking water. In waters that contain a substantial presence of cyanobacteria, bathers expose themselves through involuntary ingestion of the water and skin irritation. WHO has produced a series of guidelines for lake managers (Table 2).

In addition to the health risks associated with WBC, there are aesthetic and safety issues associated with algal bloom. Lakes with extensive algal blooms, some of which may wash up on beaches, are not attractive places for bathing. Additionally, the high turbidity associated with high nutrient content reduces swimmers underwater visibility and affects their safety.

Table 2: Guidelines for safe practice in managing which may contain cyanobacterial cells and/or toxins (WHO, 2003)

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dimethyl-7-phenylhepta-1,3-dienyl]-1,5,12,19-tetramethyl- 2-methylidene-8-(2-methylpropyl)-3,6,9,13,16,20,25-heptaoxo-1,4,7,10,14,17,21-heptazacyclopentacosane-11,22-dicar boxylicacid.

[2] The guideline value is based on the following assu mptions: Average adult body weight (bw) is 60 kg, a provisional total daily intake (TDI) set at 0.04 µg kg^{-1}, of which a proportion (P) of 0.8 is allocated to dr inking water, and water consumption of 2 L d^{-1}. It is calculated as follows: $Guideline \quad lue \quad = \frac{TI*bw*P}{L}$,which comes to 0.96 µg L^{-1}, and is rounded up to 1.0 µg L^{-1}.

Cyanobacteria Density (cells/mL)	Chlorophyll-a[3] (µg/L)	Health Risks	Recommended Action
20,000	10	Short –term adverse outcomes at low frequency: skin irritation, gastro-intestinal illness.	Post on-site risk advisory signs. Inform relevant authorities.
100,000	50	Potential for long-term illness with some cyanobacteria species. Short-term adverse health outcomes: skin irritations, gastro-intestinal illness.	Watch for scums. Restrict bathing and further investigate hazard. Post on-site risk advisory signs. Inform relevant authorities.
Cyanobacterial scum formation in bathing areas		Potential for acute poisoning. Potential for long-term illness with some cyanobacteria species. Short-term adverse health outcomes: skin irritations, gastro-intestinal illness.	Immediate action to prevent contact with scums: possible prohibition of swimming and other water-contact activities. Public health follow-up investigation. Inform relevant authorities.

There is no nationwide standard for minimum clarity to support WBC. Brezonik et al (2007) proposed Secchi depth criteria by derivation from TP criteria established by the Minnesota Pollution Control Agency. A Secchi depth of greater than 1.6 m is fully supporting, 1.21 m to 1.6 m is marginal, 0.8 m to 1.2 m is partially impaired, and less than 0.8 m is non-supporting. Iowa DNR has drafted a rule for those lakes that have public access for WBC. It sets a minimum Secchi depth of 1 m and a Chl-a limit of 25 µg/L (Iowa DNR, 2011). The National Academies of Sciences and Engineering in 1973 recommended a minimum Secchi depth of 1.2 m (Knowlton & Jones, 2003).

Annual geomeans for Secchi depth vary between the lake regions (Figure 1). Lakes in the Ozarks tend to have greater clarity than those in the plains, in part because Ozark soils have lower fertility (Knowlton & Jones, 2003). The 3rd quartile for Secchi depth in the Plains is 1.18 m, which is close to the aforementioned standard of 1.2 m.

Based on Best Professional Judgment of these lines of evidence, target Secchi depth criteria for WBC in lakes is as follows: Plains – 1.2 m; Ozark Border – 1.5 m; Ozark Highlands – 2.0 m.

[3] Applicable only if cyanobacteria are dominant in a lgal blooms.

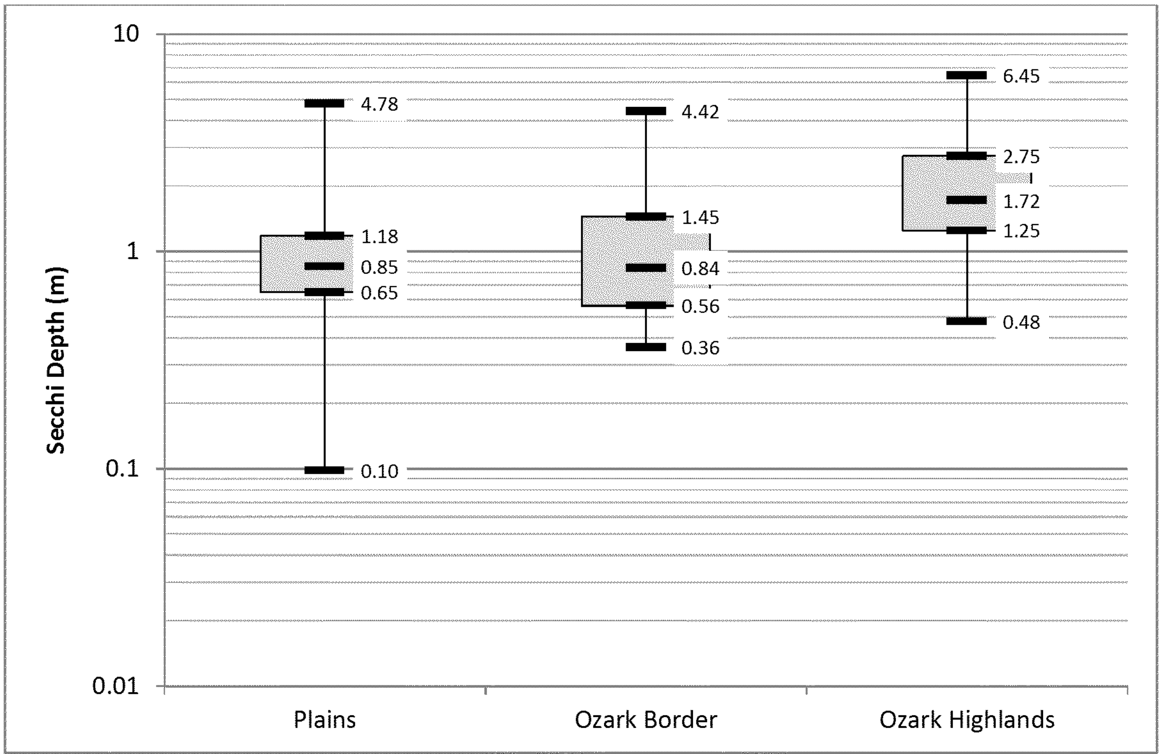

Figure 1: Boxplots for annual geomean Secchi depth in Missouri lakes. Figures include medians, interquartile, and total ranges for each region.

Secchi Depth response shows clear shifts in mean and variance in all three eco-regions as TP and TN go up in concentration (figures 2-4). This was measured with change point analysis using the nonparametric deviance reduction approach (Qian, King, & Richardson, 2003). It is based on a sequence of response variables (y) to ordered causal factors (x) which, in this case, is increasing nutrient concentration. The deviance for each level of x is calculated as follows:

$$D = \sum_{k=1}^{n} (y_k - \mu)^2$$

D = deviance; n = sample size; μ = mean of individual observations (y_k).

The deviance reduction at each increment (i) on the x-axis is then determined:

$$\Delta_i = D - (D_{\leq i} + D_{>i})$$

The point along the x-axis with the highest Δ_i is the change point. A data distribution with a significant change point will yield a Poisson distribution for Δ_i. A high value for χ^2 results in a small p-value, and the null hypothesis (no change point) can be rejected.

Modeling results are in Table 3. Modeling details are in the attachment titled “Change Point Analyses – R Program”.

Table 3: Change Point Analysis Results

	Eco-Region	Lake Annual Geomeans (n)	Regressive Partition (µg/L)	Change Point (Δ) (µg/L)	Average Secchi Depth (m)		X^2	p
					(x ≤ Δ)	(x > Δ)		
TP	Plains	432	36.5	37	1.43	0.7	5006.6	<0.001
	Ozark Border	61	28.5	26	2.05	0.7	1903.7	<0.001
	Ozark Highlands	164	13.5	13	3.07	1.37	437.7	<0.001
TN	Plains	440	710.5	707	1.39	0.76	46214.2	<0.001
	Ozark Border	61	641	616	1.79	0.66	15705.1	<0.001
	Ozark Highlands	166	366	362	2.98	1.55	14412.8	<0.001

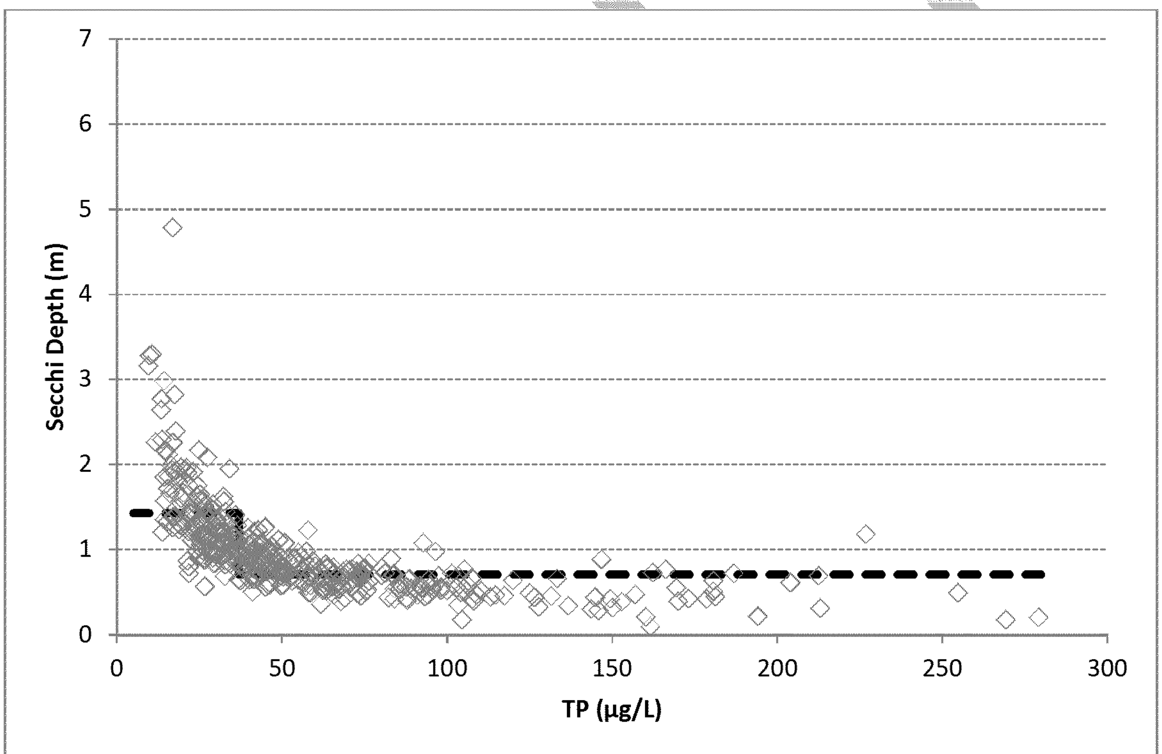

Figure 2: Change Point Analysis of Secchi Depth as a Function of Total Phosphorus in Plains Ecoregion. Vertical Dashed Line is Calculated Change Point for TP. Horizontal Dashed Lines are Averages for Secchi Depth on Each Side of Change Point.

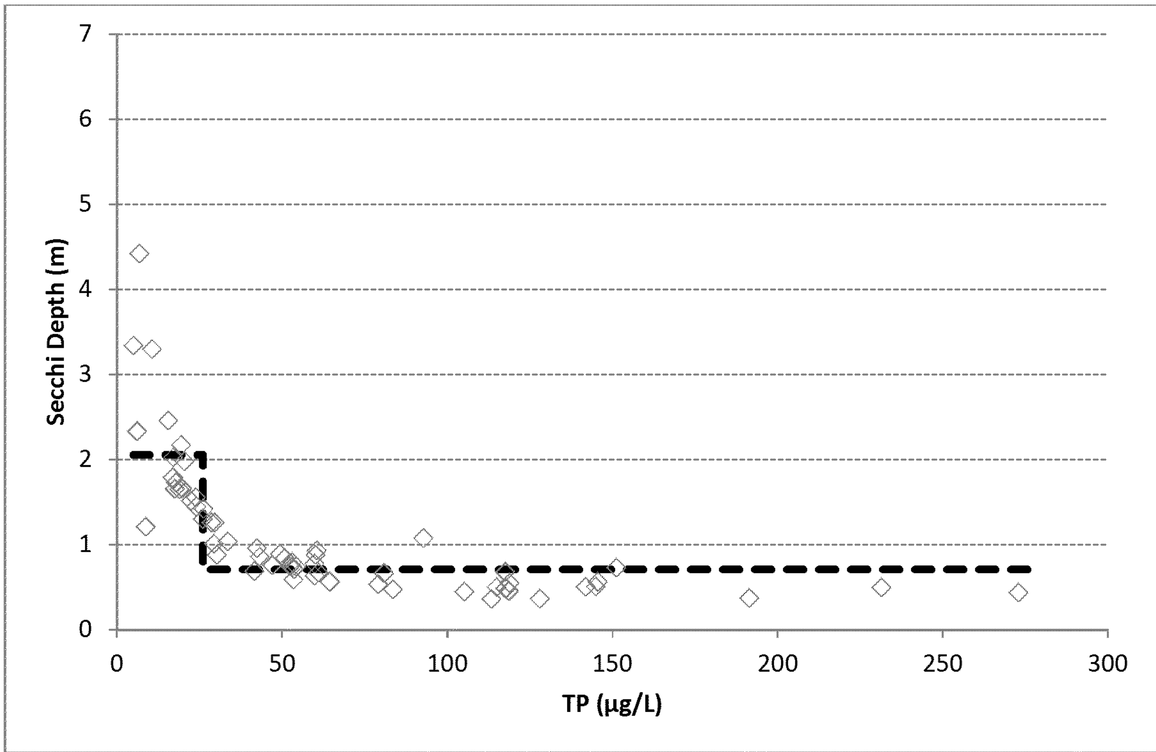

Figure 3: Change Point Analysis of Secchi Depth as a Function of Total Phosphorus in Ozark Border Ecoregion. Vertical Dashed Line is Calculated Change Point for TP. Horizontal Dashed Lines are Averages for Secchi Depth on Each Side of Change Point.

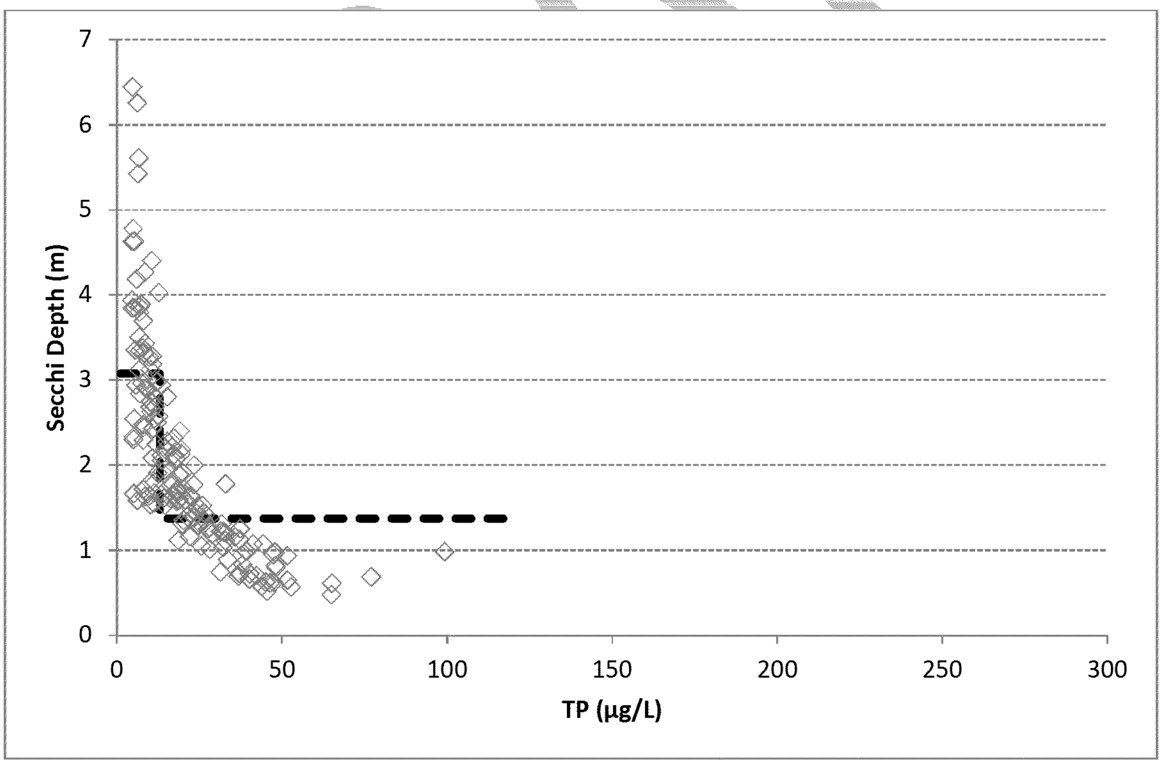

Figure 4: Change Point Analysis of Secchi Depth as a Function of Total Phosphorus in Ozark Highlands Ecoregion. Vertical Dashed Line is Calculated Change Point for TP. Horizontal Dashed lines are Averages for Secchi Depth on Each Side of Change Point.

Protection of Aquatic Habitat

Lakes in Missouri provide habitat for a variety of fish species, most of which are naturally reproducing within the lakes. Table 4 lists and describes fish species which are common in smaller lakes (<1,000 acres) (MDC, 2012).

Table 4. Common fish species that are found in the smaller lakes of Missouri.

Common Name	Scientific Name	Habitat and other comments[4]
Common Carp	*Cyprinus carpio*	Invasive species. Introduced from Asia in 1879. Abundant in man-made impoundments that are highly productive as a result of runoff from heavily fertilized farmlands or other pollutants. Often compete for food with more desirable species. Feeding habits result in deterioration of habitat through increased turbidity and destruction of aquatic vegetation.
Gizzard Shad	*Dorosoma cepedianum*	Appears in clear and turbid waters, prefers those where fertility and productivity are high.
Channel Catfish	*Ictalurus punctatus*	Common in large rivers. Hatchlings have low survival rate in clear waters, higher in turbid waters. Therefore they need periodic restocking in some lakes.
Green Sunfish	*Lepomis cyanellus*	Tolerates wide range of conditions, including extremes of turbidity, dissolved oxygen and temperature. Among the first to repopulate prairie streams following droughts.
Bluegill	*Lepomis macrochirus*	Intolerant of continuous high turbidity. Thrives in clear water where aquatic plants or other cover is present.
Redear Sunfish	*Lepomis microlophus*	Does best in warm, clear waters with no noticeable current and an abundance of aquatic plants.
Largemouth Bass	*Micropterus salmoides*	Thrives in warm, moderately clear waters with no current.
White Crappie	*Promoxis annularis*	Commonly in areas with standing timber or other cover. Spring spawning in shallow water near upper ends of coves.
Black Crappie	*Promoxis nigromaculatus*	Sporadic distribution, most prevalent in large Ozark reservoirs. Less common and less tolerant of turbidity and siltation than White Crappie.

While the ideal habitats for these species vary considerably, what they generally have in common is that they require some degree of aquatic productivity to thrive. Most of these species do well in eutrophic conditions. There is substantial literature that describes a need for higher nutrient concentrations to

[4] Summarized from descriptions by Pflieger (1975).

support healthy fisheries (Knowlton & Jones, 2003). Jones and Hoyer (1982) found a strong positive relationship between Chl-a concentrations, up to 70 µg/L, and sport fish yields in Missouri and Iowa lakes. Michaletz et al (2012) reported that growth and size structure of sport fish populations increased with water fertility, due to higher abundance of prey in more fertile waters. However there is an upper limit. They also reported, among many other findings, that for largemouth bass and black crappie, fish size distributions had a threshold for Chl-a of 40 to 60 µg/L, above which fish sizes declined. Additionally, largemouth bass and redear sunfish catch per unit effort (CPUE) were particularly low when TP exceeded 100 µg/L. This approximates the threshold of hypereutrophy (Carlson & Simpson, 1996).

In contrast to the above findings, Egertson and Downing (2004) reported that in Iowa lakes, higher concentrations of Chl-a were associated with a decline in fish species diversity. Specifically, on a Chl-a gradient of 10 to 100 µg/L, CPUE for common carp and other benthivore species went up. This appeared to be at the expense of CPUE for more desirable species, notably bluegills and black crappie. While the declines of the latter were not statistically significant, the study provides supporting evidence that highly eutrophic conditions favor benthivores and disfavor piscivores, which are mainly visual feeders.

Following a review of these and other findings, staff from the Missouri Department of Conservation and the University of Missouri made recommendations for response variables that would support warm water fisheries in smaller lakes (Table 4).

Table 4: MDC and UMC recommendations for nutrient response variable criteria for Missouri lakes.

Lake Ecoregion	Chl-a (µg/L)	Secchi depth (m)
Plains	30	0.6
Ozark Border	22	0.7
Ozark Highlands	15	0.9

<u>Human Health Protection</u>

Short term risks that are associated with the consumption of fish harvested from high nutrient environments are mainly associated with toxins in fish tissues that result from the consumption of cyanobacteria. Long term risks are largely unknown (Knowlton & Jones, 2003). At this point, there are insufficient data to establish a statistical relationship between lake nutrient concentrations and this type of risk.

<u>Secondary Contact Recreation</u>

As with HHP, risks that are associated with incidental or accidental contact with lake waters that may be impaired with high nutrient concentrations have not been well established. Furthermore, it can be assumed that such risk would be substantially lower than the risk associated with WBC.

<u>Prioritization of Designated Uses</u>

All Missouri lakes that are waters of the state have multiple designated uses as defined in 10 CSR 20-7.031 (1)(C). The most prevalent uses in upland lakes that are sensitive to nutrient content are Warm Water Habitat (WWH), Whole Body Contact (WBC), and Drinking Water Supply (DWS). In a number of lakes, particularly in the Plains region, support for WWH conflicts with the other designated uses.

WWH is defined as "Waters in which naturally-occurring water quality and habitat conditions allow the maintenance of a wide variety of warm-water biota…" Most of the lakes in Missouri are impoundments, few of which were developed before the mid-20th Century. In most cases, this was long after the landscape had been altered, principally for agricultural purposes (Jones et al, 2009).

Trophic characteristics in these lakes depend in large part on the location within the landscape where the dams were constructed and the land cover within their watersheds. These were all man made decisions. Therefore, none of the lakes in question can be identified as having natural reference conditions (Ibid). The next best thing is to aim for "maintenance of a wide variety of warm-water biota". Higher productivity in lakes has been associated with species richness as well as fish biomass (Downing & Plante, 1993). Most of the desirable species for recreational fishing are piscivores, which, within lakes, are at the top of the food chain. Abundance of these species is indicative of a healthy aquatic ecosystem.

In lakes that are sources for public drinking water (L1), protection of public health and affordable maintenance of water treatment facilities is the highest priority. In other lakes, prioritization becomes more complicated.

The L2 lakes are large enough that there is commonly an increasing gradient in trophic status from the outlet to the upper reaches (Obrecht, Jones, & Thorpe, 2005, 2008; Knowlton & Jones, 1989,1995). A lake that is mesotrophic or oligotrophic near the dam is likely to have more eutrophic conditions in the upper part of the main channel as well as in the tributary branches.

Several of the L2 lakes also have DWS as a designated use. All but one are listed for WBC-A. Since the nutrient criteria are based on samples taken from near the outlet, it is expected that maintaining response variable concentrations that are consistent with these uses will allow for all designated uses to be achievable in these lakes. This assumption will be tested by modeling these lakes using BATHTUB. This may result in changing the proposed criteria to more site-specific criteria, both for near the dam and within tributary branches.

The L3 lakes include all the rest that are classified as Waters of the State. Most of these are managed by the Missouri Department of Conservation or by private entities. Generally smaller, the primary management goal for these lakes is the propagation of healthy fish populations for recreational fishing.

There are a number of L3 lakes that are designated as WBC-A. This means that there is open access for swimming either through public facilities or written permission by a landowner. For these lakes, WBC is considered the prevailing use, and NNC will be applied accordingly. For other L3 lakes, AQL takes precedence.

Criteria Calculation

To derive criteria for each category of lakes within each lake ecoregion, regressions were run with Chl-a as the response variables. Criteria and alternate criteria for TN and TP are derived from the intersection of the positive and negative 50 percent prediction intervals (PI) of the slope and the target levels for the response variables. This approach is consistent with criteria derivation methodology published by EPA (2010a). The concept is illustrated in figure 5.

The selection of the 50 percent PI is based on a 25 percent probability that the response variable will exceed its target at the baseline criteria. This is where the upper PI of the regression line crosses the horizontal line that marks the response variable limit. If a particular lake has consistently had Chl-a concentrations at or below the limit for a period of three years despite higher nutrient concentrations, the alternative criteria allows for a TN or TP concentrations that may go up to where the lower PI crosses the horizontal (US EPA, 2010b).

For those lakes in which the WBC-A classification is the prevailing use, TN and TP criteria are derived first from change point analysis for each of the lake ecoregions. These nutrient levels are then applied to the regression equations, and a Chl-a response level is calculated. Baseline and alternative criteria are then derived using the same procedure as described above. Figures 6 and 7 illustrate the concept. The complete set of regressions that were developed for these nutrient criteria are in Appendix B.

Final criteria for nutrients and response are rounded in line with practical accuracy of measurement. TP is rounded to the nearest 10 µg/L. TN is rounded to the nearest 50 µg/L. Measurement of Chl-a and Secchi depth can be readily measured at the individual unit level (µg/L and m).

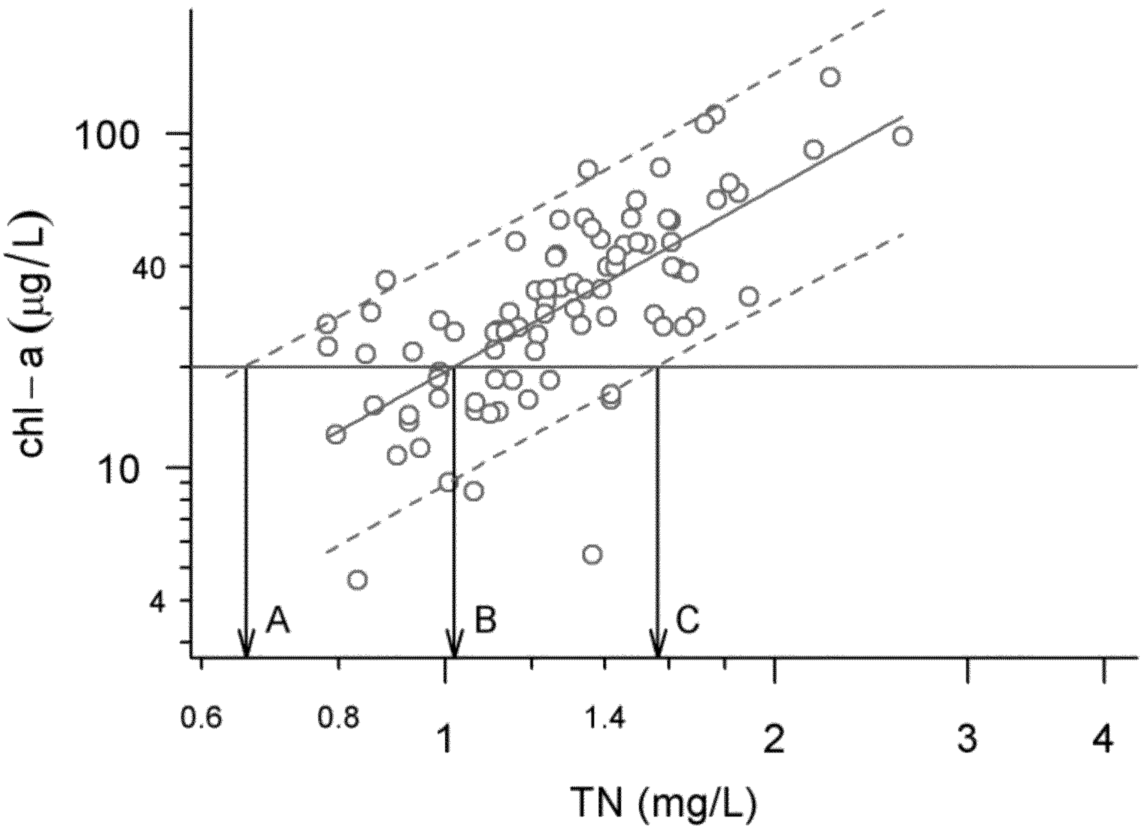

Figure 5: Total nitrogen (TN) versus chl *a* in one lake collected during March-August over 10 yea rs. Solid line: linear regression fit. Dashed lines: upper and lower 90th prediction interv als. Red horizontal line: chl *a* = 20 µg/L. Note that upper prediction interval has been extend ed beyond the range of the data to estimate the poi nt at which it intersects the chl *a* threshold. Arrows indicate candidate criteria assoc iated with different prediction intervals and the mean relationship. From EPA (2010).

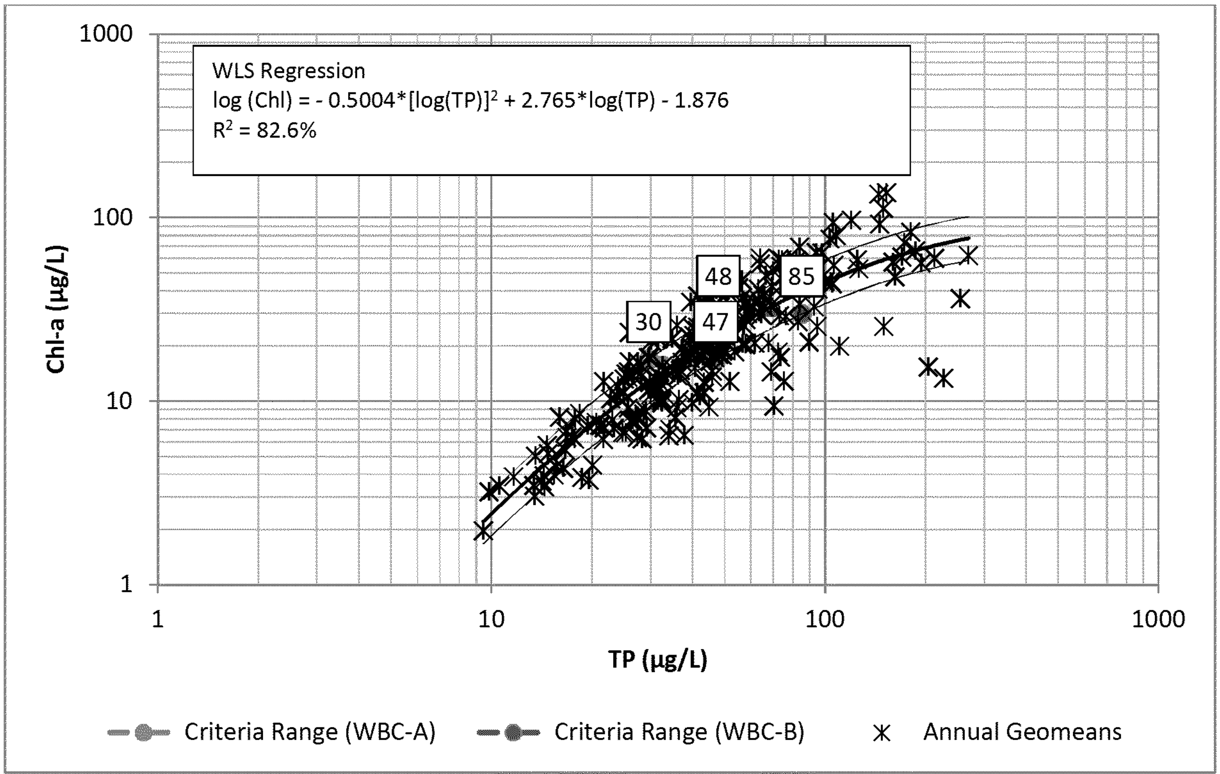

Figure 5: Regression Used to Derive TP Criteria for L3 Lakes in Plains Ecoregion

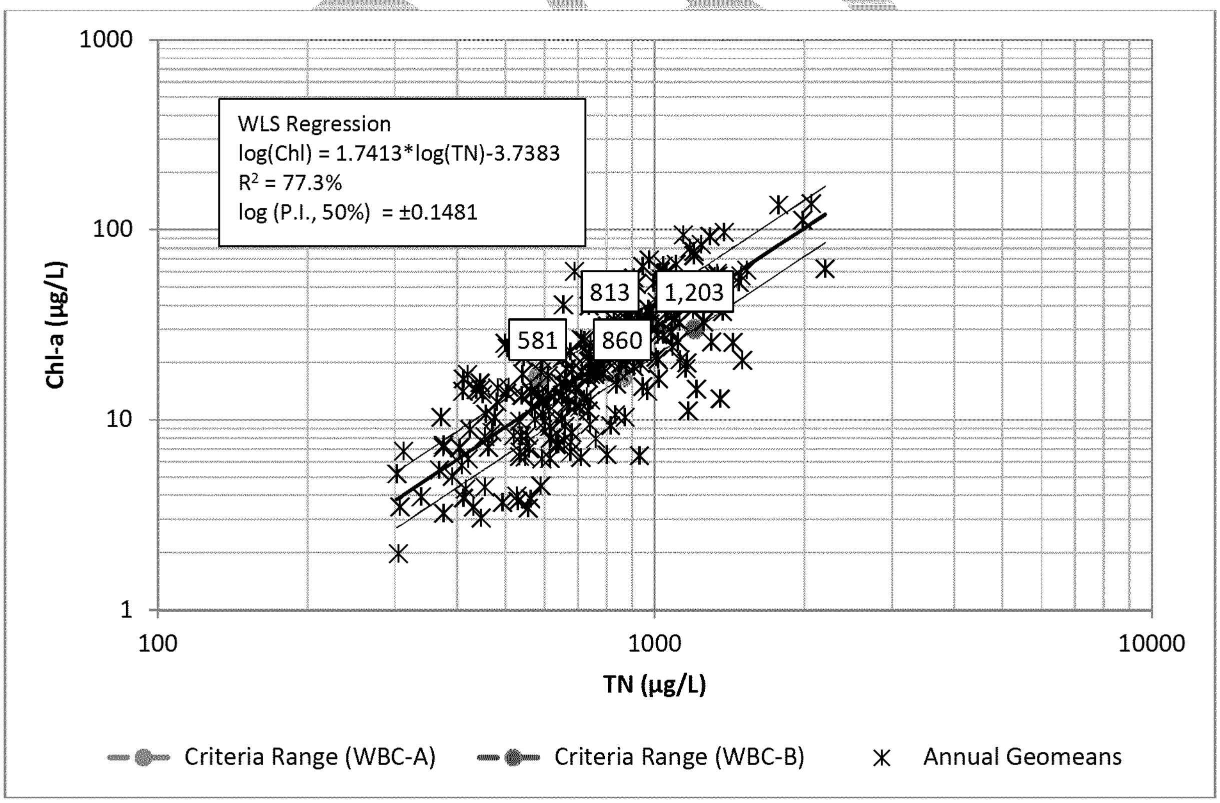

Figure 6: Regression Used to Derive TN Criteria for L3 Lakes in Plains Ecoregion

Appendix A: General statistics for lake data that were employed for this report

Region	Number of Lakes	Yearly Geomeans (n)	Parameter Concentration Averages (Ranges)			
			TN (µg/L)	TP (µg/L)	Chl-a (µg/L)	Secchi Depth (m)
Plains	111	433	864 (303 – 2200)	58 (9 – 334)	25.2 (1.8 – 132.5)	0.98 (0.1 – 4.78)
Ozark Border	22	61	882 (243 – 2576)	65 (5 – 273)	30.4 (2.8 – 99.0)	1.12 (0.36 – 4.42)
Ozark Highlands	37	164	458 (125 – 1104)	21 (4 – 99)	9.4 (0.7 – 39.5)	2.08 (0.48 – 6.45)

Appendix B: Regression Summary for Total Phosphorus (log 10 coefficients)

Region	Lake Class	n	Slope	Polynomial Factor [log (TP)]^2	Intercept	R^2 (%)	Chl-a Target (µg/L)	Baseline Target (µg/L)	Alternate Target* (µg/L)
Plains	L1	170	6.040	-1.504	-4.495	82.0	10	21	32
	L2	35	2.575	-0.7119	-1.142	69.1	12	19	43
	L3 (WBC-A)	238	2.765	-0.5004	-1.876	82.6	17	30	47
	L3 (WBC-B)						30	48	85
Ozark Border	L1**	3	6.040	-1.504	-4.495	82.0	10	20	32
	L3 (WBC-A)	58	1.213	-	-0.7864	86.8	9	19	39
	L3 (WBC-B)						22	41	78
Ozark Highlands	L1 & L2	76	1.076	-	-0.4485	86.5	4	11	16
	L3	90	0.3364	0.4332	-0.3600	89.2	15	29	38

Regression Summary for Total Nitrogen (log 10 coefficients)

Region	Lake Class	n	Slope	Polynomial Factor [log (TN)]^2	Intercept	R^2 (%)	Chl-a Target (µg/L)	Baseline Target (µg/L)	Alternate Target* (µg/L)
Plains	L1	170	11.94	-1.799	-18.18	68.6	10	447	651
	L2	31	0.7289	-	-0.9876	58.3	12	525	894
	L3 (WBC-A)	238	1.7413	-	-3.7383	77.3	17	581	860
	L3 (WBC-B)						30	813	1203
Ozark Border	L1**	3	11.94	-1.799	-18.18	68.6	10	447	651
	L3 (WBC-A)	58	10.92	-1.582	-17.04	80.0	13	522	742
	L3 (WBC-B)						22	667	1032
Ozark Highlands	L1 & L2	69	33.28	-5.965	-45.29	49.7	6	302	440
	L3 (WBC-A)	90	-5.205	1.341	5.217	73.1	5	285	445
	L3 (WBC-B)						15	597	816

*Alternate Criteria is applicable only if Chl-a criteria have been met for the immediately preceding three years.

**Included in regression for Plains.

Appendix C: Proposed Rule for Numeric Nutrient Criteria in Lakes

Missouri Department of Natural Resources

7.031(4) Specific Criteria

(N) Nutrients and chlorophyll

1. Definitions

A. For the purposes of this rule, all lakes and reservoirs shall be referred to as "lakes".

B. Lake Ecoregions – Due to differences in topography, soils and geology, nutrient criteria for lakes and reservoirs are classified by ecoregion. These regions were delineated by grouping the ecological subsections described in Nigh and Schroeder, 2002, Atlas of Missouri Ecoregions, Missouri Dept of Conservation as follows:

- **I. Plains: OP1 – Scarped Osage Plains; OP2 – Cherokee Plains; TP2 – Deep Loess Hills; TP3 – Loess Hills; TP4 – Grand River Hills; TP5 – Chariton River Hills; TP6 – Claypan Till Plains; TP7 – Wyaconda River Dissected Till Plains; TP8 – Mississippi River Hills;**
- **II. Ozark Border: MB2a – Crowley's Ridge Loess Woodland/Forest Hills; OZ11 – Prairie Ozark Border; OZ12 – Outer Ozark Border; OZ13 – Inner Ozark Border;**
- **III. Ozark Highlands OZ1 – Springfield Plain; OZ2 – Springfield Plateau; OZ3 – Elk River Hills; OZ4 – White River Hills; OZ5 – Central Plateau; OZ6 – Osage River Hills; OZ7 – Gasconade River Hills; OZ8 – Meramec River Hills; OZ9 – Current River Hills; OZ10 – St Francois Knobs and Basins; OZ14 – Black River Ozark Border;**
- **IV. Big River Floodplain: MB1 – Black River Alluvial Plain; MB2b – Crowley's Ridge Footslopes and Alluvial Plains; MB3 – St. Francis River Alluvial Plain; MB4, OZ16, TP9 – Mississippi River Alluvial Plain; OZ15, TP1 – Missouri River Alluvial Plain.**

C. Criteria Values

- **I. General Ecoregional Criteria – Limits for Total Phosphorus (TP), Total Nitrogen (TN) and Chlorophyll-a (Chl-a), in micrograms per liter (µg/L) for lakes within a lake ecoregion that have not been assigned a site specific value.**
- **II. Alternate Ecoregional Criteria - Limits for TP and TN in lakes that have not been assigned a site specific value and have not exceeded the general ecoregional criteria for Chl-a for a minimum period of three (3) consecutive years immediately preceding current assessments.**
- **III. Site Specific Criteria – Limits for TP, TN, and Chl-a for lakes that have been identified as having trophic characteristics for which the lake ecoregional values are not adequate to prevent deterioration of water quality. Lakes with site specific criteria are listed in Table M.**

D. Tributary Arm – A substantial segment of an L2 lake that is primarily recharged by a source or sources other than the main channel of the lake.

2. **This rule applies to all lakes and reservoirs that are waters of the State and that are outside the Big River Floodplain ecoregion and have an area of at least ten (10) acres during normal pool.**

3. **Lake ecoregional criteria for TP, TN, and Chl-a are listed in Table L. Site specific criteria for, TP, TN, and Chl-a are listed in Table M.**

4. **All TP, TN, and Chl-a concentrations must be calculated as the geometric mean of a minimum of three (3) representative samples per year for three (3) years that are not necessarily consecutive. All samples must be collected from the surface, near the outflow end of the lake, or at locations within tributary arms as described in Table N, and during the period May 1 - August 31.**

Table L: General Ecoregional nutrient criteria

Lake Ecoregion	Lake Class	TP (µg/L)	TN (µg/L)	Chl-a (µg/L)	Minimum Secchi Depth (m)	Alternative Criteria TP (µg/L)	Alternative Criteria TN (µg/L)
Plains	L1	20	450	10.0	1.2	30	650
	L2	20	550	12.0	1.2	40	900
	L3 (WBC-A)	30	600	17.0	1.2	50	850
	L3 (WBC-B)	50	800	30.0	0.6	90	1,200
Ozark Border	L1	20	450	10.0	1.5	30	650
	L3 (WBC-A)	20	500	9.0	1.5	35	700
	L3 (WBC-B)	40	650	22.0	0.7	80	1,050
Ozark Highlands	L1 & L2	10	300	6.0	2.0	20	450
	L3 (WBC-A)	10	300	6.0	2.0	20	450
	L3 (WBC-B)	30	600	15.0	0.9	40	800

Table M: Lakes with site specific criteria

Lake Ecoregion	Lake	County	Site specific criteria (µg/L) TP	TN	Chl-a
Plains	Bowling Green Lake	Pike	21	502	6.5
	Bowling Green Lake (old)	Pike	31	506	5.0
	Forest Lake	Adair	21	412	4.3
	Fox Valley Lake	Clark	17	581	6.3
	Hazel Creek Lake	Adair	27	616	6.9
	Lincoln Lake – Cuivre River State Park	Lincoln	16	413	4.3
	Marie, Lake	Mercer	14	444	3.6
	Nehai Tonkaia Lake	Chariton	15	418	2.7
	Viking, Lake	Daviess	25	509	7.8
	Waukomis Lake	Platte	25	553	11.0
	Weatherby Lake	Platte	16	363	5.1
Ozark Border	Goose Creek Lake	St Francois	12	383	3.2
	Wauwanoka, Lake	Jefferson	12	384	6.1
Ozark Highlands	Council Bluff Lake	Iron	7	229	2.1
	Crane Lake	Iron	9	240	2.6
	Fourche Lake	Ripley	9	236	2.1
	Loggers Lake	Shannon	9	200	2.6
	Lower Taum Sauk Lake	Reynolds	9	203	2.6
	Noblett Lake	Douglas	9	211	2.0
	St. Joe State Park Lakes (Monsanto)	St Francois	9	374	2.0
	Sunnen Lake	Washington	9	274	2.6
	Table Rock Lake	Stone	9	253	2.6
	Terre du Lac Lakes	St Francois			
	- Capri		6	284	1.3
	- Carmel		8	319	1.7
	- Marseilles		9	330	1.6
	Timberline Lake	St Francois	8	276	1.5

Table N: Total Phosphorus Criteria in tributary arms of major reservoirs

Reservoir	Tributary Arm	Sample Site (dec. deg.) Latitude	Longitude	TP (µg/L)
Ozarks, Lake of the	Grand Glaize	38.11	-92.664	26
	Gravois	38.245	-92.745	26
	Niangua	38.071	-92.822	26
Table Rock Lake	James River	36.678	-93.535	16
	Kings River	36.576	-93.596	18
	Long Creek	36.557	-93.294	12

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